



BALLARD™



**FORSEE
POWER**

Optimized Fuel Cell Electric Powertrains for Trucks

Ballard and Forsee Power value proposition for truck applications

March 2025

Optimized for Performance

As heavy-duty transport shifts towards zero-emission vehicles, the choice of powertrain technology becomes critical. For fuel cell electric trucks, balancing and optimizing fuel cell and battery power is essential to achieve maximum efficiency, performance, and operational longevity. This balance impacts overall energy efficiency, vehicle range, load capacity, and total cost of ownership (TCO).

Combining Ballard's expertise in fuel cells with Forsee Power's capabilities in smart battery systems, the partnership leverages the strengths of both companies to deliver integrated hybrid energy systems. These systems optimize energy usage and efficiency for heavy-duty truck applications, ensuring that vehicles meet the rigorous demands of the industry while minimizing environmental impact.

BALLARD™

- High power, market-leading fuel cell engines
- Deep knowledge of fuel cell hybridization approaches
- System modeling capabilities



Ballard FCmove®-XD

Forsee Power PULSE PLUS



FORSEE POWER

- Deep understanding of battery technology
- High power battery packs, suited for fuel cell applications
- Battery lifetime modeling

A Balanced Solution

The battery and fuel cell represents 30-40% of the cost of a fuel cell electric truck, and up to 70-80% of the powertrain cost. Working with experienced partners helps to ensure that the balance of fuel cell and battery power delivers the highest level of performance for the truck, based on different use cases.

Key considerations for truck OEMs, fleet operators, and end-users when choosing a truck with the lowest lifecycle costs include:



Availability: Ensuring vehicles are reliable, robust and road-ready at all times



Optimized TCO: Long lifetime and optimized amortization of the fleet



Maintenance: Delivering technical support throughout the vehicle's lifetime – from integration to maintenance



Control Strategy: Optimizing the control strategy at powertrain level, improving range and fuel efficiency

How to select the right battery and fuel cell products for your truck?



Weight

Mass of battery and fuel cell



Control Strategies

Range, fuel efficiency, etc.



Performance

Range, fuel efficiency, etc.



Integration

Engine bay or rooftop mounting



Cost

CAPEX, OPEX, TCO, etc.

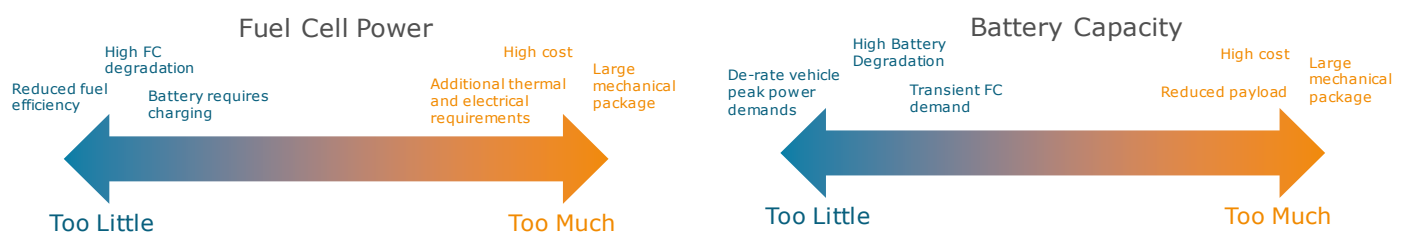
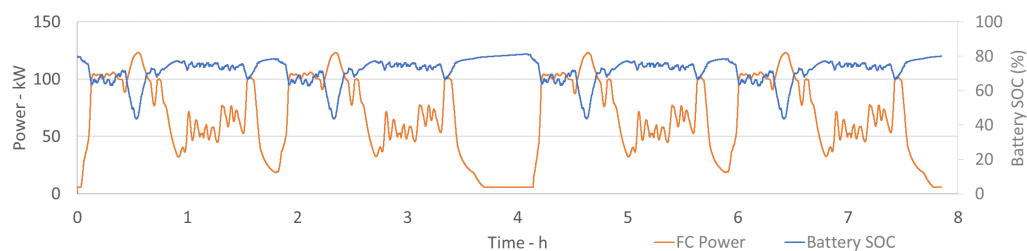




Choosing the Best Battery and Fuel Cell Combination

It is important to arrive at a suitable balance between the fuel cell power and battery capacity/power for the specific truck use case. Modeling many different fuel cell and battery configurations can help converge on the optimal approach.

In addition, control and operating strategies are important considerations for OEMs and integrators, and can have significant impact on the selection of the battery and fuel cell.



Design Principles

Combined with system modeling, the following six design principles can provide a useful guide to define component configuration:

- 1 Ensure the fuel cell can provide more than the average power requirements of the duty cycle
- 2 Select a battery technology that can deliver the peak power requirement of the vehicle
- 3 Size the battery capacity so the battery state of charge stays within an acceptable range and can provide the full electric range required by the customer
- 4 Size the battery and fuel cell according to the lifetime of the vehicle and its requirements to avoid additional replacement costs
- 5 Compare the economics with the simulated results, to find the optimal performance/cost ratio

Requirements

Capacity

Results





Choosing the Right Battery

Balancing the health of the fuel cell and the battery is important when designing a well optimized fuel cell truck. Forsee Power and Ballard can work together to help you define the best component configuration and control strategy to optimize performance, and extend the lifetime of both the fuel cell and the battery.



ZEN PLUS

High energy density
Light weight package
350A peak
145A cont.



PULSE PLUS

High power density
Lifetime performance
600A peak
300A cont.

Forsee Power offers a wide range of battery solutions for Class 6-8 fuel cell electric trucks

OEMs and integrators can choose between **high power batteries** (Forsee PULSE) or **high energy batteries** (Forsee ZEN). Each configuration offers different characteristics and some may be better suited than others in specific use cases. The task is to find the best compromise, balancing factors such as energy, power, acquisition cost, TCO, integration, weight, cyclability, lifetime, etc.

Battery solutions for Class 6 fuel cell delivery trucks

PULSE PLUS (2 x 26kWh LTO) Very high-power system allowing a flexible control strategy and excellent lifetime performance

ZEN PLUS (2 x 84kWh NMC) Higher full electric range and offers a more versatile solution

Battery solutions for Class 8 fuel cell trucks

PULSE PLUS (2 x 26kWh LTO) Very high power system, very stable chemistry with long lifetime performance

Efficiency and Lifetime of Your Powertrain with the Support of Ballard and Forsee Power

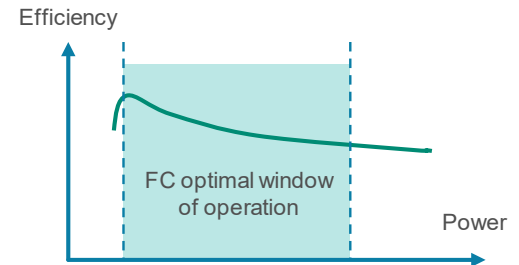
Well chosen components and control strategies will benefit both efficiency and lifetime.

Fuel Cell

BALLARD™

WHILE DESIGNING YOUR CONTROL STRATEGY, CONSIDER THE FOLLOWING FOR THE FUEL CELL:

- Stay in the high efficiency window
- Avoid frequent on/off cycling
- Avoid operating at high load when stack coolant temperature is low
- Avoid high temperature operation (stack) for a long time
- Run at stable operation - minimizing fuel cell power dynamics can significantly improve stack lifetime

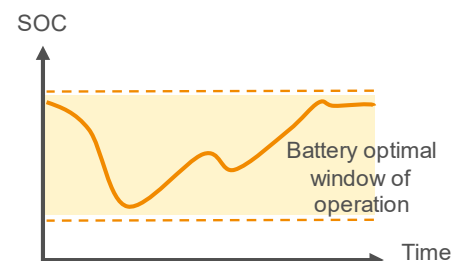


Battery

**FORSEE
POWER**

TO OPTIMIZE YOUR BATTERY CONTROL STRATEGY, ENSURE YOU:

- Stay in the optimal SOC window
- Align charge/discharge current to selected technology
- Adapt charge/discharge current with ambient temperature and cooling strategy





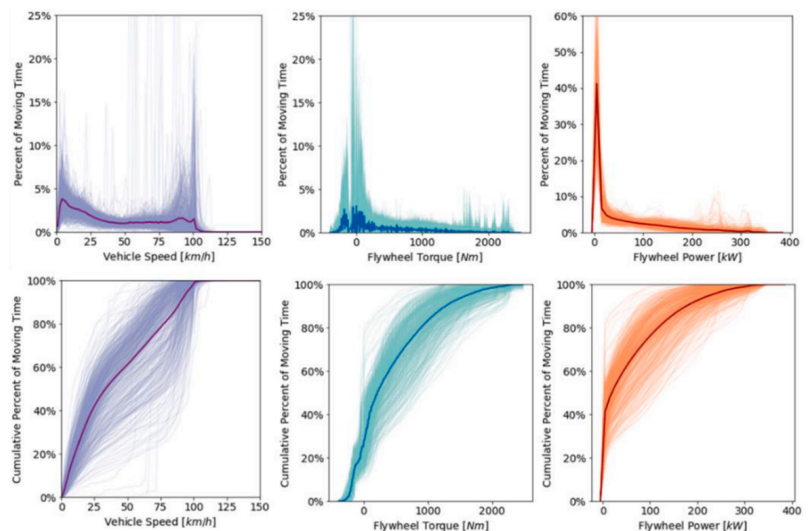
Fleet Representative Duty Cycle

Looking at representative duty cycles for Class 6-8 trucks, data from the U.S. National Renewable Laboratory's (NRL) research paper provides representative samples. NRL's study of "heavy-duty vehicle representative driving cycles via decision tree regression" used a database of over 2,700 recorded vehicles with more than 18 million driven kilometers to derive representative cycles for different classes of vehicles in the following categories:

- Drayage
- Long Haul
- Regional Haul
- Local Delivery
- Transit Bus

Each vehicle had cycles synthesised to represent the following drive cycles:

- Representative Average Cycle
- Maximum Cycle
- Maximum High Speed
- Maximum Power Weighted Work
- Maximum Trip Distance
- Minimum MPG



The following Class 6 and 8 use cases are based on speed traces along with assumed vehicle parameters to model the power demand of the trucks for the relevant cycles. Long haul and regional haul cycles were used to create a range of Class 8 power traces. Local delivery cycles were used to create the Class 6 cycles.

Focus: Class 6 Delivery Truck Use Case

When modeling a truck's optimal powertrain, it is essential to have a good data set that is representative of real-world conditions and operations.



Route

FOCUS ON THE DUTY CYCLE



Highway Cycle

Distance: 950km

Duration: 12h7

Average speed: 74km/h

Total mean power: 79kW

Local Delivery

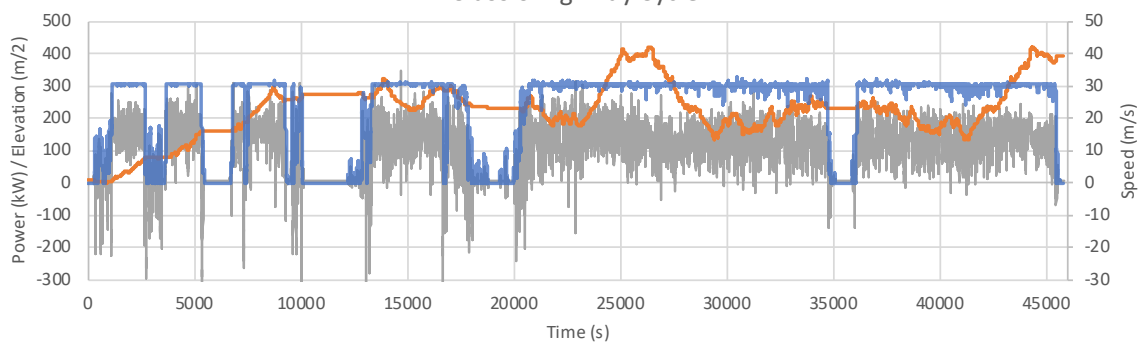
Distance: 187km

Duration: 5h

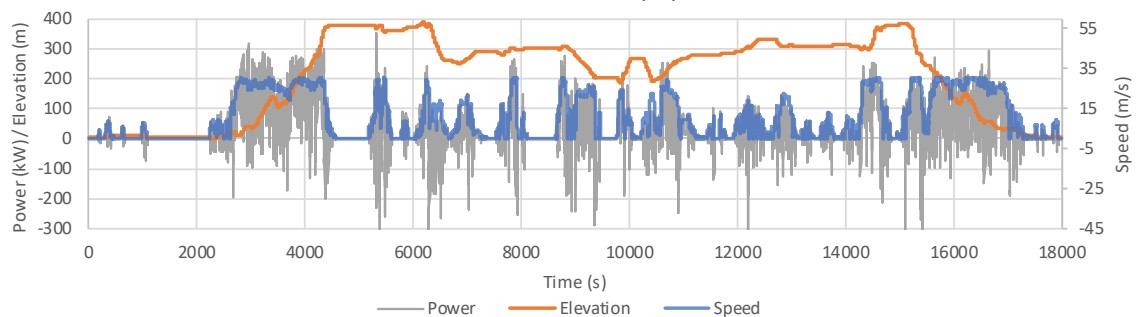
Average speed: 37km/h

Total mean power: 36kW

Class 6 Highway Cycle



Class 6 Local Delivery Cycle



Focus: Class 8 Long Haul Truck Use Case



Route

FOCUS ON THE DUTY CYCLE



Regional Cycle

Distance: 690km

Duration: 9h9

Average speed: 70km/h

Total mean power: 116kW

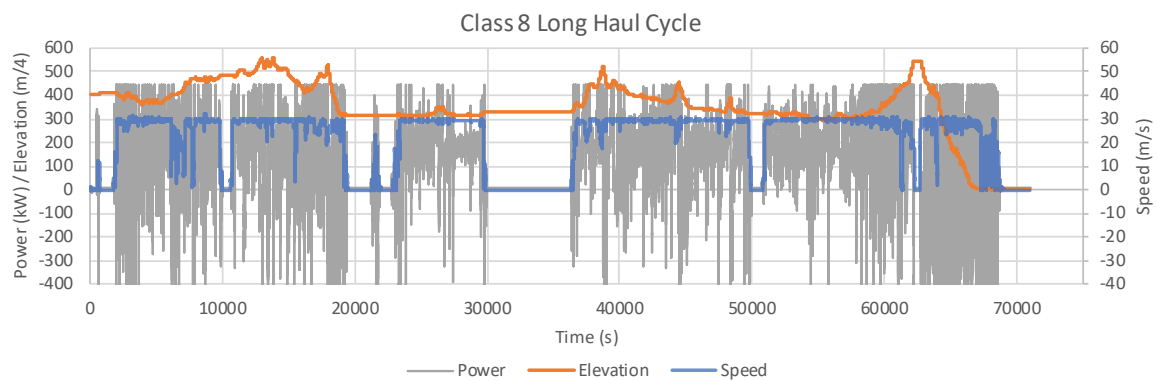
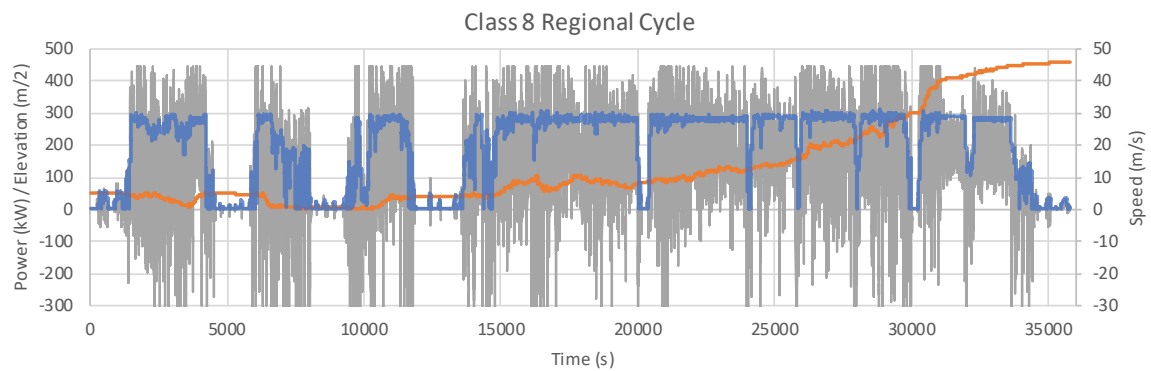
Long Haul Cycle

Distance: 1510km

Duration: 19h

Average speed: 76km/h

Total mean power: 120kW



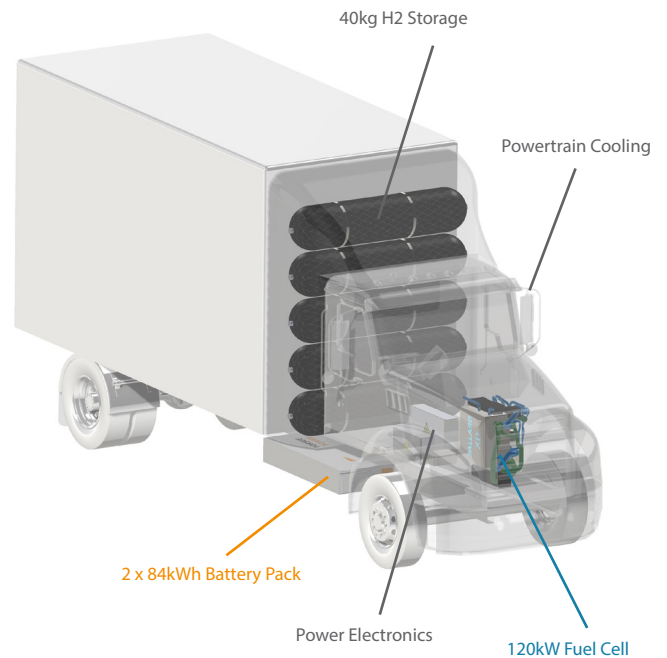
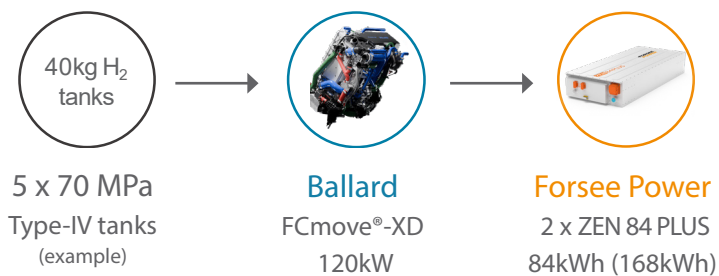
Optimal Solution

CLASS 6 DELIVERY TRUCK

The range of the vehicle with 40kg H₂:

Highway cycle ~ 527km (50% fuel cell efficiency)

Delivery cycle ~ 520km (53% fuel cell efficiency)

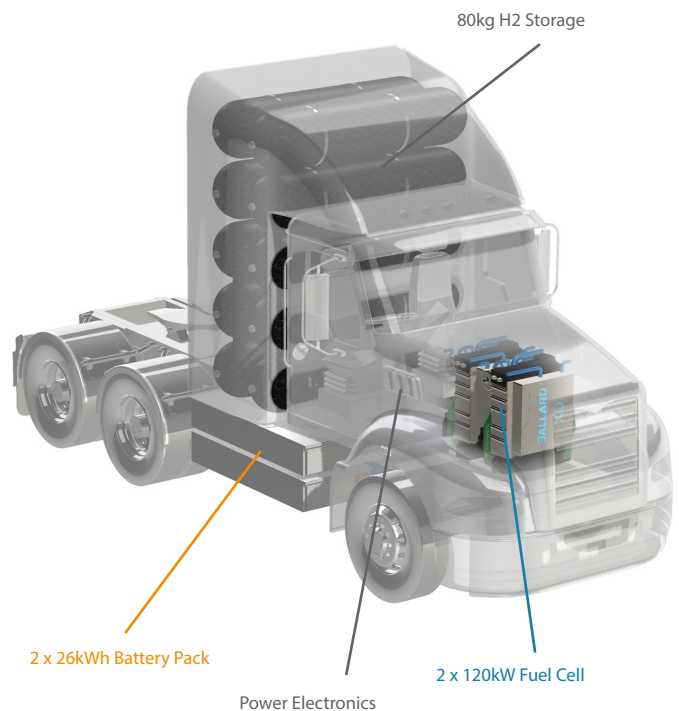
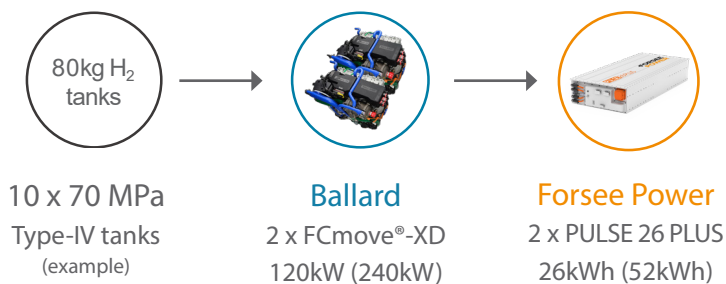


CLASS 8 TRUCK

The range of the vehicle with 80kg H₂:

Regional cycle ~ 625km (51% fuel cell efficiency)

Long haul cycle ~ 646km (50% fuel cell efficiency)



BALLARD™



FORSEE POWER

Our Promise and Added Value

- Proven battery and fuel cell technologies (+5,000 buses and trucks on the road*)
- Large range of fuel cell engines and battery chemistry and packaging
- Deep understanding of lifetime and degradation modes
- In-house modelling tools to help you improve your hybridization strategy
- Optimization of space requirement, packaging and mechanical integration
- Committed service teams to support your deployments
- Industrial footprint in three regions: North America, Europe and China

*since 2015

BALLARD™

Ballard Power Systems
ballard.com

**FORSEE
POWER**

Forsee Power
forseepower.com